Sampling and Survey with AUVs in Adverse Weather Conditions

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1 LONG-TERM GOALS

The general objective is to investigate the basic and applied problems associated with the efficacious reconnaissance of littoral waters in support of mine warfare and oceanographic tasks. Specifically with this proposal, we wish to quantify the shallow-water performance of the sensor systems and platforms in relation to harsh environmental conditions and high sea states. In particular for platforms we wish to address the performance issues with respect to navigation, communication, control and conditional mission planning during which the underwater acoustic propagation properties are severely affected by the bubble formation and mixing properties induced by storm fronts. We wish to address design and implementation problems associated with our current docking design and performance in stormy conditions.

2 OBJECTIVES

Numerical details of mixing and acoustic properties in such adverse weather conditions remain poorly understood mainly due to the lack of experimental data for quantitative modeling and correlation analysis. During a storm passage, the induced weather condition can become so severe that surface ships are rendered inoperable for collecting during-storm measurements. One approach is to deploy beforehand a network of moored sensors. A moored system is hampered by logistical problems in deploying all sensors in a short period of time and also the deployment cost can be excessive when wide area volumetric synoptic coverage is required. It is thus of significant scientific and military interest to devise suitable underwater mobile sensing platforms which enable us to characterize the four dimensional transfer dynamics of oceanic processes synoptically. By capitalizing on the AUV technology, shallow-water oceanographic measurements in adverse weather conditions using multiple AUVs can provide a cost-effective solution in understanding the cause and effect of a storm passage. The basic idea is to provide a fixed underwater platform where an AUV can be docked with battery recharge and data upload facilities while the AUV waits for the storm. The AUV then leaves the dock during the storm to perform a volumetric survey and concludes by docking and waiting until after the storm for recovery.

The South Florida Ocean Measurement Center (SFOMC) is a consortium of several institutions, namely FAU, USF, NOVA, U of Miami, NSWC, and HBOI. SFOMC is instrumenting a shallow water range off Dania Florida. This range will have data a power cables to shore. An AUV dock will be attached to a MUX that distributes power and data amongst several planned installations.

The primary goal of this project is to develop docking capability and provide suitable AUV plat-

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form support for experiments during adverse weather with the AUV. Specific technical goals to be addressed in this proposal are 1) to determine the limits of AUV navigation, control and communication in poor environmental conditions. 2) to evaluate the reliability of rendezvous, docking and recharge mechanisms to be used during the storm passing; 3) to develop software tools to process large volumes of data collected over several missions, and to integrate the data with standard of-the-shelf commercial tools using standard formats such as HDF. This project only addresses the AUV survey, navigation, communication, and docking development issues. The sensor development work is budgeted for in other proposals. The ship and range costs for the actual experiment are budgeted for in the SFOMC proposal.

3 APPROACH

3.1 Methods

The experiment site is chosen to be within the SFOMC range just south of Fort Lauderdale inlet, and the location will be in shallow water 5 to 50 meters deep. This range is advantageous for this experiment because it includes a measurement range in 15m of water which allows for the hardwiring of sensors directly to shore. This will allow for the deployment of instrumentation before a period of adverse weather and for continuous onshore monitoring and evaluation of the data during the storm.

The dock will be a modified version of the system currently in development and testing at FAU. The dock will have a powerline feed to shore for recharging the docks batteries. The dock will have data storage for receiving uploads of AUV data and energy storage batteries to recharge the AUV. The AUV docks with a belly mounted stinger and puck assembly. Docking is performed similarly to an aircraft landing on a carrier. The dock is a bottom mounted assembly with “V” shaped slots to capture the puck on the end of the stinger. A clover leave arrangement of 4 channels allows docking from any direction. The main reason for a belly mounted approach is to preserve the modular nature of OEX payloads. With a belly mounted stinger most payloads can be used without modification for docking missions. For example, the turbulence sensors must be mounted on the nose of the vehicle and are very fragile. They are incompatible with nose mounted docking approaches such as employed by the Odyssey or the REMUS.

The puck will house a power connector and an RF antennae. An ethernet RF modem will be used to transfer data between the AUV and dock. Another RF antennae is mounted in the dock a couple of inches away from the puck when docked. Sea water experiments have shown that at this short distance RF signals will propagate between the antennas. An acoustic modem on the dock will allow the vehicle to communicate with the dock when it is nearby. Local positioning information is provided by a short base line acoustic system composed of 3 transducers mounted on a framework of aluminum pipes. This provides positioning accuracies on the order of 6” rms. The dock will be located in 40 - 50 ft. of water. This is to minimize wave disturbances while still being shallow enough for divers to reach.

3.2 Experiments

The experimental work was divided into two tracks. Track 1 focused on further development and testing of the docking navigation and mechanical system. Track 2 focused on supporting the collecting data in adverse weather conditions. Two major experiments were planned one for the second quarter of 1999 and the other for the fourth quarter. Only one of the experiments was funded.The docking development work was carried out during the first 3 quarters of 1999.

The sensors on board the AUVs would consist of a turbulence probe, DGPS, DVL, LBL, SBL, Acoustic Modem, and CTD. These would allow the measurement of sound velocity profiles, currents, and turbulence.

4 WORK COMPLETED

The new Dive Tracker SBL system was integrated into an OEX payload. The navigation algorithm was extensively modified and tested to get the required < 12 in navigational accuracy. During March about 20 AUV runs were conducted to test tracking consistency. Static tests revealed good tracking accuracy. Dynamic tests showed reasonable fidelity as well. Operations ceased until August due to the ACOMS and 4 D current experiments use of the vehicles.

In August the navigator and position estimator on the AUV were modified to support navigation using the SBL. A total of 24 docking navigation missions were conducted. Each mission lasted approximately 10 minutes and was in most cases a simple ‘out and back’ configuration, with the return leg oriented to allow the vehicle to approach the docking balloon from down current. These were all performed using the Magellan AUV operating off the Oceaneer IV. Each of these missions was an attempt to navigate the AUV within a pre-defined limit of a tethered buoy floating mid water. The buoy was located approximately 5 m from the fixed sea-floor mounted SBL array. A nose mounted video camera recorded the approach to the dock from onboard the AUV.

The mechanical dock was completed and at sea non-powered tests of the latching mechanism with the stinger attached to the AUV were successful. What remains to be are powered docking runs.

A set of adverse weather sampling missions were conducted during July. Unfortunately the weather did not cooperate and a storm front was not encountered. However significant long duration turbulence data sets were collected. The actual analysis of this data is provided for in companion proposals.

5 RESULTS

The dock horizontal capture aperture is +- 0.5 meter. After some adjustment to controller and position estimator parameters, we were able to repeatedly swim the AVU to within 1 meter of a moored (12 inch diameter) target. In half the runs it flew to within 0.5 meters of the target and in one third of the runs it hit the target. The navigation accurately measured the position of the AUV. The misses were due to the controller not the position estimation. Since we used a simple track-line controller for these tests it is felt that further refinement to the controller will result in a much higher success ratio.

Table 5.1: **Mission Results**

Mission	Target Location	AUV Cross Track Error	Diver Observed Error	Post Mission Corrected Error
1643	5.4 m East	0.4m West	<1mW	<0.8mW
1653	5.4	0.4m West	<1mW	<0.8mW
1701	5.4	0.2m West	Hit Target	<0.2mE
1728	6.0	0.3m West	<1mE	<0.6mE

Table 5.1: **Mission Results**

Mission	Target Location	AUV Cross Track Error	Diver Observed Error	Post Mission Corrected Error
1747	5.6	1m East	<0.2mE	<0.2mE
1756	5.6 m East	0.5m West	HIT Target	HI Target
1812	5.6	0.0	HIT Target	HIT Target
1844	5.6	1.5m East	<0.5mE	<0.5mE
1853	5.6	0.8m West	<1mW	<1mW

In all of these missions the AUV passed within 1m of the buoy. The first 4 missions used a target location of 5.4 m East. Since the AUV consistently passed to the west the pre programmed target location was moved to 5.6 m East. After that all the missions were within the capture aperture. The AUV is capable of achieving the ball within a +/- 0.45m corridor. The altitude and depth accuracy of the vehicle is within +- 0.1 meters. The navigation system and mechanical docking system have been shown to be feasible approaches to docking. This approach although more complicated than nose mounted systems does not interfere with modular nose mounted payloads such as turbulence sensors. The cloverleaf capture mechanism is much smaller than other nose mounted systems used in other approaches.

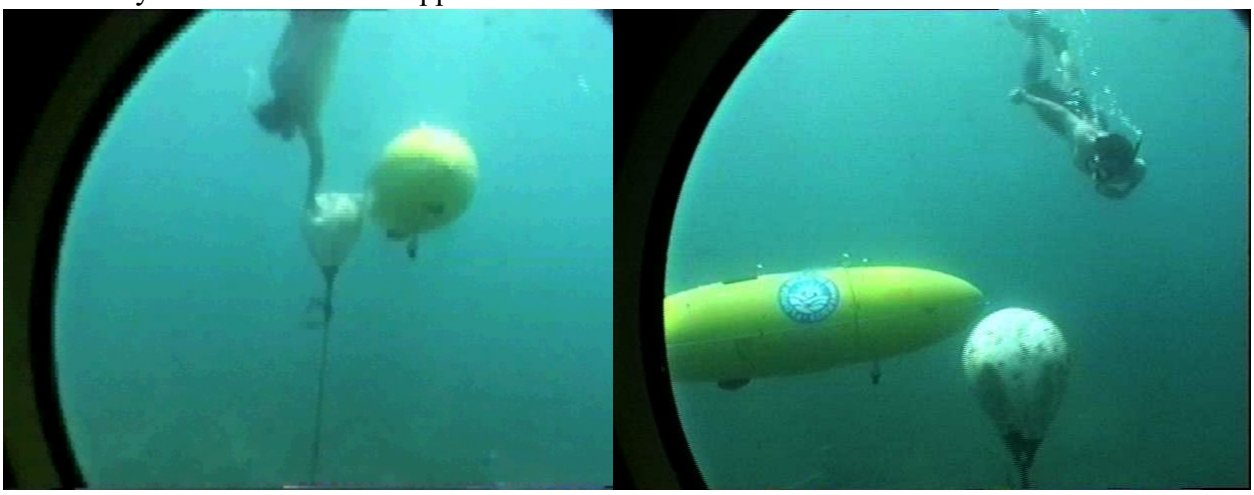

*Figure 5.*1 Mission 1853, Approach shows depth and horizontal position accuracy

Figure 5.2 Onboard AUV video as it approaches target.

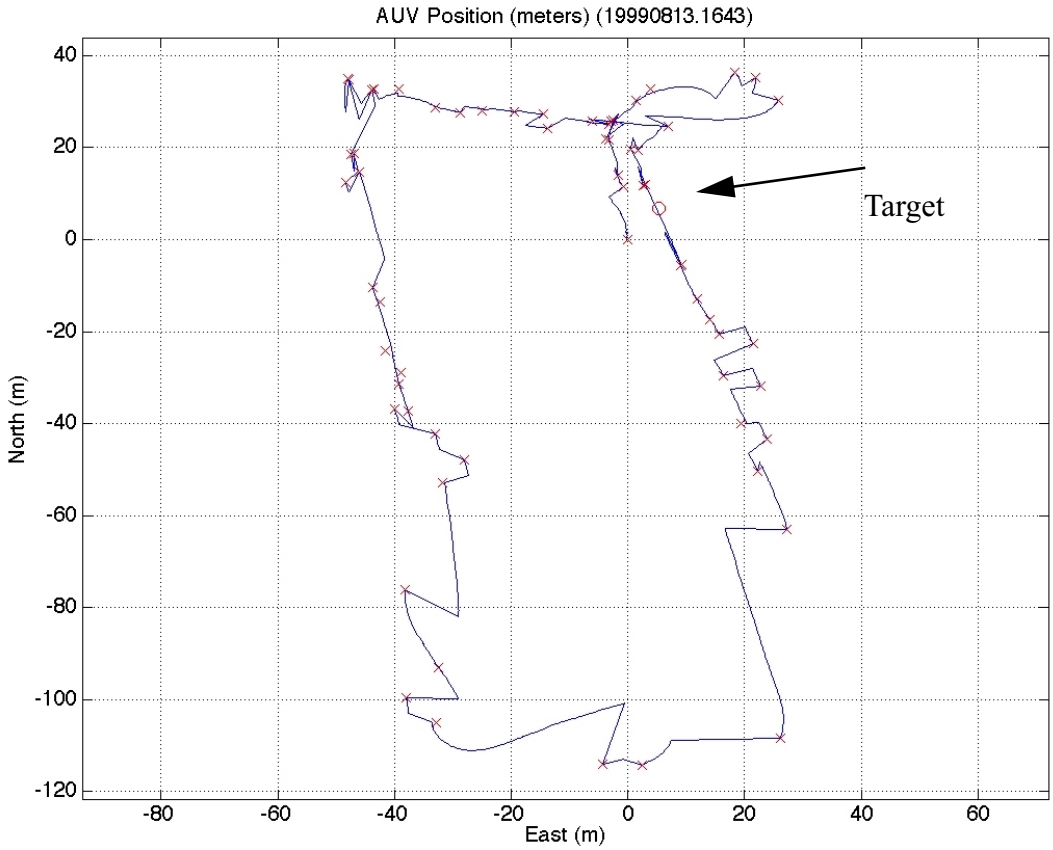

Figure 5.3 Plot of docking run. X's represent SBL fixes.

6 IMPACT/APPLICATIONS.

Successful docking capability will allow measurements with AUVs in sea conditions not economically or technically feasible in other ways. This will allow mapping of bubble cloud formation and frontal passage. Power and recharge from docks with significantly extend mission durations and allow for longer term sampling and covert deployment of AUV for rapid environmental assessment and shallow water MCM tasks.

7 RELATED PROJECTS

.Coordination of Experiments Using AUVs at the SFTF, ONR.

AUV Hydrodynamics in Shallow Water during Adverse Weather Conditions, ONR.

Acoustic Communications with AUVs and AOSN Development

AUV Navigation and Platform Development

Remote Sampling and Survey of Shallow Water Using AUVs w/application to Mine Reconnaissance and operations support for experiments using the FAU AUVs.

Sampling and Survey with AUVs in Adverse Weather Conditions

ONR MURI on Nonlinear Control

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